

1 TO WHOM IT MAY CONCERN:

2

3 BE IT KNOWN THAT WE, MORRIS F. DILMORE, a  
4 citizen of the United States of America, residing in  
5 Baker, in the County of Okaloosa, State of Florida,  
6 HENRY S. MEEKS, III, a citizen of the United States of  
7 America, residing in Roseville, in the County of  
8 Placer, State of California, and Marc S. Fleming, a  
9 citizen of the United States of America, residing in  
10 Rancho Cordova, in the County of Sacramento, State of  
11 California, have invented a new and useful improvement  
12 in

13

14 METAL CONSOLIDATION PROCESS APPLICABLE TO FUNCTIONALLY

15 GRADIENT MATERIAL (FGM) COMPOSITIONS OF TANTALUM

16 AND OTHER MATERIALS

17

18

19

20

21

22

23

24

25

## BACKGROUND OF THE INVENTION

2

3

3                   This application is a continuation-in-part of  
4   prior U.S. patent application Serial No. 09/551,248,  
5   filed April 18, 2000, incorporated herein by reference.

6                   This invention relates generally to the field  
7 of consolidating hard metallic bodies, and also to  
8 rapid and efficient and heating and handling of  
9 granular media employed in such consolidation, as well  
10 as rapid and efficient heating and handling of preform  
11 powdered metal or metal bodies to be consolidated,  
12 where such bodies consist essentially of functionally  
13 gradient materials, designated herein as FGM. Such  
14 materials when consolidated exhibit along a body  
15 dimension or dimensions decreased or varying strength  
16 or ductility (strain hardening).

17                   · The technique of employing carbonaceous  
18 particulate or grain at high temperature as pressure  
19 transmitting media for producing high density metallic  
20 objects is discussed at length in U.S. Patents Nos.  
21 4,140,711, 4,933,140 and 4,539,175, the disclosures of  
22 which are incorporated herein, by reference.

23 The present invention provides improvements  
24 in such techniques, and particularly improvement  
25 leading to consolidation of bodies consisting

1 essentially of functionally gradient material (FGM)  
2 compositions. One example is tantalum or tantalum  
3 together with other metals. Such metals, one or more  
4 of which may be consolidated with tantalum, include  
5 tungsten, copper, hafnium, rhenium, platinum, gold,  
6 molybdenum, uranium, titanium, zirconium and aluminum.

7

## SUMMARY OF THE INVENTION

9

10 It is a major object of the invention to  
11 provide for consolidation of metallic powder consisting  
12 of selected metals as referred to, and as may be  
13 employed in target penetration, drilling, and related  
14 impact activities. Such selected metals typically are  
15 distributed as FGMs, as referred to.

16                   It is another object of the invention to  
17  provide rapid and efficient heating of carbonaceous  
18  and/or ceramic particles used as pressure transmitting  
19  media, and also transfer of heat generated in the  
20  particles to the work, i.e. the hard metal preform to  
21  be consolidated. Basic steps of the method of  
22  consolidating the preform metallic body in any of  
23  initially powdered, sintered, fibrous, sponge, or other  
24  form capable of compaction, or densification (to reduce  
25  porosity) then include the steps:

1                   a)    providing flowable particles having  
2   carbonaceous and ceramic composition or compositions,  
3                   b)    heating the particles to elevated  
4   temperature,  
5                   c)    locating the heated particles in a bed,  
6                   d)    positioning the preform body at the bed,  
7   to receive pressure transmission,  
8                   e)    effecting pressurization of said bed to  
9   cause pressure transmission via said particles to the  
10   body, thereby to compact the body into desired shape,  
11   as for example cylindrical shape, increasing its  
12   density, and  
13                  f)    the body consisting essentially of one  
14   or more metals selected from the following group:  
15   tungsten, rhenium, uranium, tantalum, platinum, copper,  
16   gold, hafnium, molybdenum, titanium, zirconium and  
17   aluminum,  
18                  g)    the consolidated body having, along a  
19   body dimension, one of the following characteristics:  
20                   i)    decreasing strength  
21                   ii)   increasing ductility  
22                   iii)  decreasing strength, and increasing  
23                    ductility.

24

25

26

1                   Another object is to achieve rapid or almost  
2 instantaneous densification of a composite metal alloy  
3 system, the resultant material being fine grained,  
4 isotropic, and maintaining original metastable  
5 microstructures.

6                   A further object is to produce a consolidated  
7 functionally gradient material (FGM) for use as a  
8 shaped, heavy metal penetrator EFP (explosively formed  
9 penetrator) or SCL (shaped charge lines) . One highly  
10 advantageous and particular FGM material powder system  
11 is comprised of a tantalum and other heavy metal  
12 powdered alloy outer section, and transitioning to a  
13 different density based powder. It may include an  
14 intermediate layer of metal matrix composite of the  
15 heavy metal alloy, and lower density powder, and a  
16 monolithic lower density base section. The powdered  
17 material system for process A may typically employ  
18 tantalum particles coated with a pre-alloyed binder  
19 composition but other elementally blended, mixed or  
20 otherwise combined particles are applicable. The total  
21 binder may typically consist of elemental metals  
22 selected from the group tungsten, copper, tantalum,  
23 hafnium, rhenium, platinum, gold, molybdenum, and  
24 uranium hereinafter referred to as HMG, of  
25 approximately 16 weight percent of the total  
26 composition; but other compositions may be employed.

1 The powdered material system for a process B may  
2 typically employ transition layers of one metal to the  
3 next with the build-up based on requirements.

4 The ability to fabricate a functionally  
5 gradient heavy metal penetrator in one single forging  
6 operation has several advantages. The first is the  
7 ability to design and engineer a penetrator with  
8 specific and predictable dynamic performance criteria.  
9 The second advantage is that of reduced manufacturing  
10 costs directly related to fewer hot forging steps.  
11 Additional cost reductions are realized in the area of  
12 raw material usage by eliminating forging trim and  
13 scrappage resulting from the use of a powder  
14 metallurgy, near net shape forging preform.

15 By the use of the methodology of the present  
16 invention, substantially improved structural articles  
17 of manufacture can be made having minimal distortion,  
18 as particularly enabled by the use of carbonaceous, or  
19 ceramic, or carbonaceous/ceramic particulate in  
20 flowable form.

21 An additional object includes provision of  
22 a method for consolidating hard metal and/or ceramic  
23 powder, and/or composite material with or without  
24 polymeric powder, to form an object, that includes

25 a) pressing the FGM into a preform, and  
26 preheating the preform to elevated temperature,

5 c) positioning the FGM preform in such  
6 relation to the bed that the particles substantially  
7 encompass the preform,

13 The preform typically consists of tantalum complex with  
14 metals selected from the HGM group as referred to.

15 An additional object is to provide a body to  
16 be consolidated having varying metallic composition  
17 along a body dimension. That varying composition may  
18 be characterized by a series of zones, extending either  
19 axially or radially for example along the article's  
20 axis, each zone having a characteristic composition  
21 which differs from that of an adjacent zone or zones.

22 The metal in successive zones may consist of at least  
23 consolidated tantalum, and tantalum consolidated  
24 together with one or more metals from the HGM group,  
25 and also steel, but in varying proportions in  
26 successive zones. For a projectile having great

1 penetration capability, a tapered nose zone may consist  
2 primarily of tantalum, and successive zones to the rear  
3 may contain less and less tantalum and more and more  
4 steel.

5 For a three metal body, the metals being  $M_1$ ,  
6  $M_2$  and  $M_3$ , the weights  $W_1$ ,  $W_2$  and  $W_3$  per unit volume of  
7 the respective metals  $M_1$ ,  $M_2$  and  $M_3$ , are related and  
8 selected, to be as follows:

9  $W_1 > W_2 > W_3$

10

11 Other objects are to provide consolidated  
12 bodies such as tapered shells, and/or cylindrical and  
13 tapered bodies, made by the method of the invention,  
14 and having functional gradient properties in two  
15 dimensions.

16 The novel features which are believed to be  
17 characteristic of this invention, both as to its  
18 organization and method of operation, together with  
19 further objectives and advantages thereof, will be  
20 better understood from the following description  
21 considered in connection with the accompanying drawings  
22 in which a presently preferred embodiment of the  
23 invention is illustrated by way of example. It is to  
24 be expressly understood, however, that the drawings are  
25 for the purposes of illustration and description only

1 and are not intended as a definition of the limits of  
2 the invention.

## DRAWING DESCRIPTION

4

5 Fig. 1 is a flow diagram showing method steps  
6 of the present invention;

7 Fig. 2 is a cut-away elevation showing the  
8 consolidation step of the present invention;

9                   Fig. 3 is a vertical section showing preform  
10                  pressurization, prior to consolidation;

11 Fig. 4 is a view like Fig. 3, showing a  
12 modified preform;

Fig. 5 is a view of a consolidated preform;

14 Fig. 6 shows a tantalum particle with layers  
15 of  $Z_1$ ,  $Z_2$ , and  $Z_3$  as found in a matrix;

16 Fig. 7 is a section taken through multiple  
17 layers of different metals;

18 Figs. 8a and 8b are side and bottom views of  
19 a consolidated shaped charge liner (SCL) formed by the  
20 method of the invention; and

21 Figs. 9a and 9b are side and bottom views of  
22 a consolidated explosively formed penetration (EFP)  
23 formed by the method of the invention.

1

DETAILED DESCRIPTION

2

3           Referring first to Fig. 1, there is shown a  
4 flow diagram illustrating method steps of the present  
5 invention. As can be seen from numeral 10, initially a  
6 metal, metal and ceramic, or ceramic article of  
7 manufacture or preform is made, for example, in the  
8 shape of a penetrator or other body or impact tool such  
9 as a drill or other product. One preferred embodiment  
10 contemplates the use of a metal preform made of  
11 powdered tantalum, partially coated with one or more  
12 HGM particles, then mechanically blended with a low  
13 alloy steel powder. Preferably, tantalum constitutes  
14 more than 50% of the overall weight of the preform.  
15 Other metallic or ceramic particles or coatings may  
16 also be included. See for example Fig. 6 showing  
17 tantalum particles 100 coated with or surrounded by  
18 metals  $Z_1$ ,  $Z_2$ , and  $Z_3$ , in a preform. A preform  
19 typically is about 60 to 85 percent of theoretical  
20 density after the powder has been made and compacted  
21 into a preformed shape, and it may typically  
22 subsequently be sintered (see step 12 in Fig. 1) in  
23 order to increase the strength. In the preferred  
24 embodiment, the preform in billet form is subjected to  
25 cold or ambient temperature isostatic compaction at

1 about 60,000 pounds per square inch, preferably within  
2 an evacuated and sealed elastomeric (rubber) container.  
3 See for example Fig. 3 showing evacuated, sealed  
4 elastomeric container 110, with the preform 111 located  
5 therein, and shaped in the form of a cylinder. Fig. 5  
6 is like Fig. 3, but shows the preform 112 shaped in the  
7 form of a cylinder and having a tapered end 112a, for  
8 penetration of hard targets. Fluid pressure is  
9 supplied at 113 to the interior 114 of a metal vessel  
10 115 within which the tantalum, and other powdered metal  
11 ( $M_1$ ,  $M_2$ , etc.) preform, and its elastomeric container  
12 are located, to pressurize the container and compact  
13 the powder preform. Once the billet preform has been  
14 compacted to about 60% of theoretical density, it is  
15 heated in a protective or reducing atmosphere, such as  
16 Argon or hydrogen, to above 900°C, in preparation for  
17 consolidation. See step 14 in Fig. 1. Alternative  
18 steps include step 12 sintering in Fig. 1, and re-  
19 heating at 14.

20 The consolidation process, illustrated at 16  
21 in Fig. 1, takes place after the hot preform (removed  
22 from 110 and 115) has been placed, as for example in a  
23 bed of heated carbonaceous or carbonaceous/ceramic  
24 particles as hereinbelow discussed in greater detail.  
25 Consolidation takes place by subjecting the embedded

1 preform to elevated temperature and high pressure. In  
2 a preferred embodiment, temperatures in the range of  
3 about 1,600°F. and uniaxial pressures of about 5 to 100  
4 and higher TSI are used, for compaction. The preform  
5 has now been densified and can be separated, as noted  
6 at 18 in Fig. 1, whereby the carbonaceous particles  
7 separate readily from the preform and can be recycled  
8 as indicated at 19. If necessary, any particles  
9 adhering to the preform can be removed and the final  
10 product can be further finished, as for example  
11 machined.

12 Final product dimensional stability, to a  
13 high and desirable degree, is obtained when the  
14 particle (grain) bed primarily (and preferably  
15 substantially completely) consists of flowable  
16 carbonaceous and/or ceramic particles. For best  
17 results, such carbonaceous particles are resiliently  
18 compressible graphite beads, and they have outward  
19 projecting nodules on and spaced part on their  
20 generally spheroidally shaped outer surfaces, as well  
21 as surface fissures. See for example U.S. Patent  
22 No. 4,640,711. Their preferred size is between 50 and  
23 240 mesh. Useful granules are further identified as  
24 desulphurized petroleum coke. Such carbon or graphite

1 particles have the following additional advantages in  
2 the process:

- 3       1. They form easily around corners and  
4           edges, to distribute applied pressure  
5           essentially uniformly to and over the body  
6           being compacted. The particles suffer very  
7           minimal fracture, under compaction pressure.
- 8       2. The particles are not abrasive, therefore  
9           reduced scoring and wear of the die is  
10          achieved.
- 11      3. They are elastically deformable, i.e.  
12           resiliently compressible under pressure and  
13           at elevated temperature, the particles being  
14           stable and usable up to 4,000°F.; it is found  
15           that the granules, accordingly, tend to  
16           separate easily from (i.e. do not adhere to)  
17           the body surface when the body is removed  
18           from the bed following compaction.
- 19      4. The granules do not agglomerate, i.e.  
20           cling to one another, as a result of the  
21           body compaction process. Accordingly, the  
22           particles are readily recycled, for reuse, as  
23           at 19 in Fig. 1.
- 24      5. The graphite particles become

1                    rapidly heated in response to passage of  
2                    electrical current or microwaves  
3                    therethrough. The particles are stable and  
4                    usable at elevated temperatures up to  
5                    4,000°F. Even though graphite oxidizes in  
6                    air at temperatures over 800°F. Short  
7                    exposures as during heatup and cooldown, do  
8                    not substantially harm the graphite  
9                    particles.

10                  Referring now to Fig. 2, the  
11                  consolidation step is more completely illustrated. In  
12                  the preferred embodiment, the preform 20 (as for  
13                  example preform 111 in Fig. 3 or preform 111a in Fig.  
14                  4) has been completely embedded in a bed of  
15                  carbonaceous particles 22 as described, and which in  
16                  turn have been placed in a contained zone 24a as in  
17                  consolidation die 24. Press bed 26 forms a bottom  
18                  platen, while hydraulic press ram 28 defines a top and  
19                  is used to press down onto the particles 22 which  
20                  distributes the applied pressure non-isostatically (30%  
21                  deformation (compression) axially - 10% deformation  
22                  (tensile) radially) to the preform 20. The preform is  
23                  at a temperature between 200°C. and 1,800°C., prior to  
24                  compaction. The embedded metal powder preform 20 is  
25                  rapidly compressed under high uniaxial pressure by the

1 action of ram 28 in die 24, the grain having been  
2 heated to between 400°C. and 4,000°F. Pressurization  
3 is typically effected at levels greater than about  
4 20,000 psi for a time interval of less than about 30  
5 seconds. Particles may be located within a sub-bed in  
6 a deformable container, in bed 22.

7 Referring again to Fig. 2, a heating furnace  
8 50 is shown, incorporating a fluidized bed of grain  
9 particles, to be supplied at 51 to die 24. Such PTM  
10 can be a carbonaceous and ceramic composite of varying  
11 composition ranging from 5 to 95 percent, by volume, of  
12 ceramic particles, the balance being carbonaceous  
13 particles. Usable ceramics include: aluminum oxide,  
14 boron carbide or nitride, and other hard ceramic  
15 materials. The heater may comprise an electrical  
16 resistance heater, or a microwave heater, for example.

17 Fig. 4 shows a preform 111a, similar to that  
18 at 111 in Fig. 3; however, the metal composition of the  
19 preform varies along its length direction, indicated by  
20 arrow 140. A stratified overall composition is  
21 indicated by multiple layers as for example at 142-145.  
22 Each layer may consist of one or more of powder form  
23 metals  $M_1$  and  $M_2$  (or mixture thereof), or metals  $M_1$ ,  $M_2$   
24 and  $M_3$  (or mixtures thereof), or metals  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$ ,  
25  $M_5$ , and  $M_6$  (or mixtures thereof). The selection of

1 metals and mixtures, and their proportions as by  
2 weight, may be such as to produce an ultimate  
3 consolidated article wherein the strength and ductility  
4 of the article (at zones corresponding to layers 142-  
5 145) varies, in the length direction 140; for example  
6 the hardness may decrease, progressively, in direction  
7 140.

8 In Fig. 4, each layer may consist of one or  
9 more of powder form metals  $M_1$  and  $M_2$  (or mixture  
10 thereof), or metals  $M_1$ ,  $M_2$  and  $M_3$  (or mixtures thereof),  
11 or metals  $M_1$ ,  $M_2$ ,  $M_3$  and  $M_4$  (or mixtures thereof), or  
12 metals  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$  and  $M_5$  (or mixtures thereof), or  $M_1$ ,  
13  $M_2$ ,  $M_3$ ,  $M_4$ ,  $M_5$ , and  $M_6$  (or mixtures thereof). Again, the  
14 selection of metals may be such that ultimate strength  
15 decreases and ductility increases, progressively and  
16 stepwise, in direction 140. Thus, for example, the  
17 layer 142 consists of the very strong high density  
18 metal such as tantalum adapted for high velocity  
19 penetration of armor plate, or other hard target  
20 structures such as reinforced concrete and steel,  
21 underground bunkers such as those used to protect  
22 chemical and biological weapons of mass destruction  
23 (WMD). The opposite end layer 145 may consist  
24 primarily of copper, etc. for high ductility and  
25 performance.

1                   Layer 142 may consist of particles of  
2                   tantalum encapsulated within layers of one or more HGM  
3                   metal particles, and defined as powder A.   Layer 145  
4                   may consist of particles of low alloy steel, defined as  
5                   powder B.   Intermediate layers 143 and 144 may consist  
6                   of mixtures of powder A and powder B, where the  
7                   percentage by weight of powder A decreases in  
8                   successive layers in direction 140, and the percentage  
9                   by weight of powder B in successive layers increases in  
10                  direction 140.

11                  One example of the transition layer  
12                  composition in Fig. 4 would be as follows:

13                  Layer 142 consists primarily of powder A  
14                  Layer 143 consists of 80% powder A and 20% powder B  
15                  Layer 144 consists of 60% powder A and 40% powder B  
16                  A further layer if used consists of 40% powder A and  
17                  60% powder B

18                  A further layer if used consists of 20% powder A and  
19                  80% powder B

20                  Layer 145 consists of 100% powder B  
21                  A further definition of the composite is as  
22                  follows: the body may be of a SCL or EFP shape as  
23                  discussed rates, the body consisting of at least two  
24                  metals,  $M_1$  and  $M_2$ , the proportions of  $M_1$  and  $M_2$  in said  
25                  body nose portion and second body portion being

1 different. For example, the metal  $M_1$  is tantalum, the  
2 proportion of tantalum in that nose portion being  
3 greater than the proportion of tantalum in said second  
4 body portion. Further, the body has third and fourth  
5 body portions along said dimension, the proportion of  
6 tantalum in said second body portion exceeding the  
7 proportion of tantalum in said third body portion, and  
8 the proportion of tantalum in said third body portion  
9 exceeding the proportion of tantalum in said fourth  
10 body portion.

11 In addition, the body has first and second  
12 ends, the consolidated metal at the first end having  
13 higher density than the consolidated metal at the  
14 second end; and wherein the metal at the first end  
15 consists primarily of tantalum, and the metal at the  
16 second end consists primarily of a different density  
17 and performance characteristic material, i.e.,  
18 pyrophoric.

19 Fig. 5 shows by way of example a product 160  
20 shaped generally like that of the preform 111a. The  
21 product 160 has been pressure consolidated, as  
22 described, to reduce its size from preform size  
23 indicated by the broken lines 161. Forward portion 162  
24 consists essentially of tantalum; the next layer  
25 portion 163 in sequence consists of 20% by weight of a  
26 lower density metal (LDM) and the balance tantalum; the

1 next layered portion 164 in sequence consists of 40%  
2 lower density metal (LDM) and the balance tantalum; the  
3 next layered portion 165 in sequence consists of 60%  
4 lower density metal and the balance tantalum; the next  
5 layered portion 166 in sequence consists of 80% lower  
6 density metal (LDM) and the balance tantalum; and the  
7 last layer 167 consists essentially of LDM. The layer  
8 thicknesses can be adjusted to lower increments to  
9 improve the FGM bond.

10 The process of the invention yields a fully  
11 dense microstructure and metallurgically sound bonds at  
12 180-184, across the layered zones 162-167.

13 In Fig. 7 a "Process B" formed shape 120  
14 consists of metallic layers 121-123 with decreasing  
15 strength in direction 124. The layers are consolidated  
16 as described above. Typical layers are:

17 121 - tantalum

18 122 - copper

19 123 - aluminum

20 Density decreases in direction 124.

21 In Figs. 8a and 8b, a shaped charge liner 80  
22 has conical shell form, with a base 81, convex nose 82,  
23 outer side wall 83 tapering toward 82, and inner side  
24 wall 84 tapering toward 82. Wall 84 surrounds or forms  
25 inner cavity 85. The liner is formed by the method of  
26 the invention, i.e. is a consolidated body, and has FGM

1 property (decreasing strength and/or ductility) in  
2 axial length direction 87; and FGM property (decreasing  
3 hardness and/or toughness) in wall thickness direction  
4 88, those directions indicated by arrows, as shown.  
5 Thus, the outer side is more ductile than the inner  
6 side, and the nose 82 is more ductile than the base 81.

7 In Figs. 9a and 9b, a penetrator 90 has  
8 combined cylindrical and tapered shape (as at sections  
9 90a and 90b as shown), and is a solid body. Section  
10 90b tapers toward tip 91. The penetrator is formed by  
11 the method of the invention, i.e. is a consolidated  
12 body, and has FGM property (increasing strength and/or  
13 ductility in axial length direction 93; and FGM  
14 property (decreasing strength and/or ductility) in  
15 center-to-side directions 94. Those directions are  
16 indicated by arrows as shown. Thus, the tip 91 and  
17 tapered wall 96 are stronger than the base 98; and body  
18 outer side 99 is stronger than body center 100.

19 In Figs. 10a and 10b, an EFP body 110 is  
20 shown in side and bottom views. A body hollow 111 is  
21 formed below a domed top 112.

22 In each of Figs. 8a, 8b, 9a, 9b, 10a, and  
23 10b, the body at its toughest zone may consist of  
24 tantalum, and at less tough zone may consist of  
25 tantalum complexed with metal or metals selected from  
26 the above HGM group.

1                   The basic preferred method of consolidating a  
2 body in any of initially powdered, sintered, fibrous,  
3 sponge, or other form capable of compaction, that  
4 includes the steps:

5                   a) providing flowable pressure transmission  
6 particles having carbonaceous and ceramic composition  
7 or compositions,

8                   b) heating said particles to elevated  
9 temperature,

10                  c) locating said heated particles in a bed,  
11                  d) positioning said body at said bed, to  
12 receive pressure transmission,

13                  e) effecting pressurization of said bed to  
14 cause pressure transmission via said particles to said  
15 body, thereby to compact and consolidate the body into  
16 desired shape, increasing its density;

17                  f) the body consisting essentially of one  
18 or more metals selected from the following group:

19 tungsten, rhenium, uranium, tantalum, platinum, copper,  
20 gold, hafnium, molybdenum, titanium, zirconium and  
21 aluminum;

22                  g) said consolidated body having, along a  
23 body dimension, one of the following characteristics:

24                   i) decreasing strength  
25                   ii) increasing ductility

3                   Typically, the body has varying metallic  
4 composition along said dimension; and the varying  
5 metallic composition is characterized by a series of  
6 zones, the metal of each zone having a characteristic  
7 composition which differs from that of an adjacent zone  
8 or zones. Further, the metals in at least two  
9 successive zones consist substantially of tantalum, and  
10 tantalum consolidated with a metal or metals selected  
11 from the group tungsten, rhenium, uranium, tantalum,  
12 platinum, copper, gold, hafnium, molybdenum, titanium,  
13 zirconium and aluminum.

14                           The body may consist of powders of metals  
15                           that have been initially combined and compressed into  
16                           body form, at pressure exceeding 20,000 pounds per  
17                           square inch, prior to said step e) pressurization. At  
18                           least part of the body has one of the following forms:

19 i) cone

20 ii) lens

#### iv) cylinder and cone combination

23 v) cylinder and lens combination.

24 The disclosure of U.S. Patent Application

25 Serial No. 09/239,268 is also incorporated herein, by

1 reference. Accordingly, the consolidated tantalum may  
2 have <111> texture less than about 2.8X random.

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26